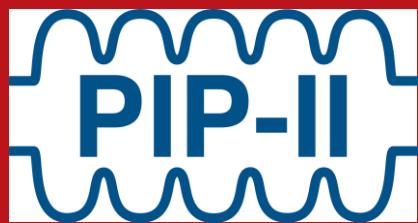




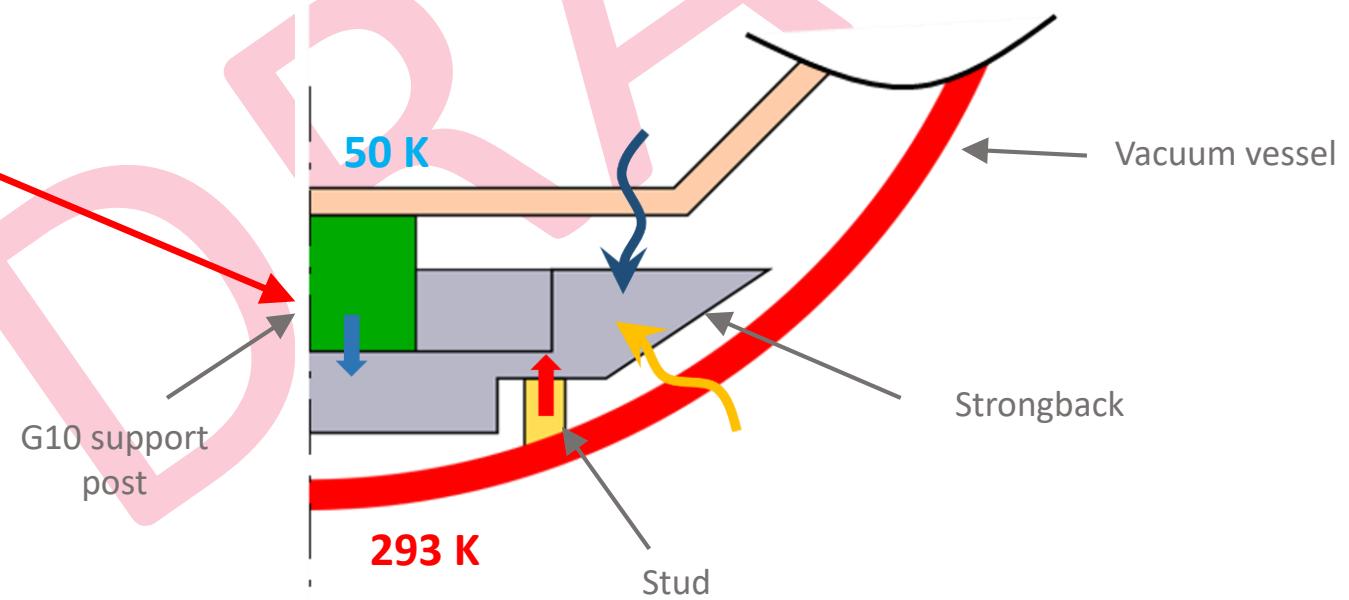
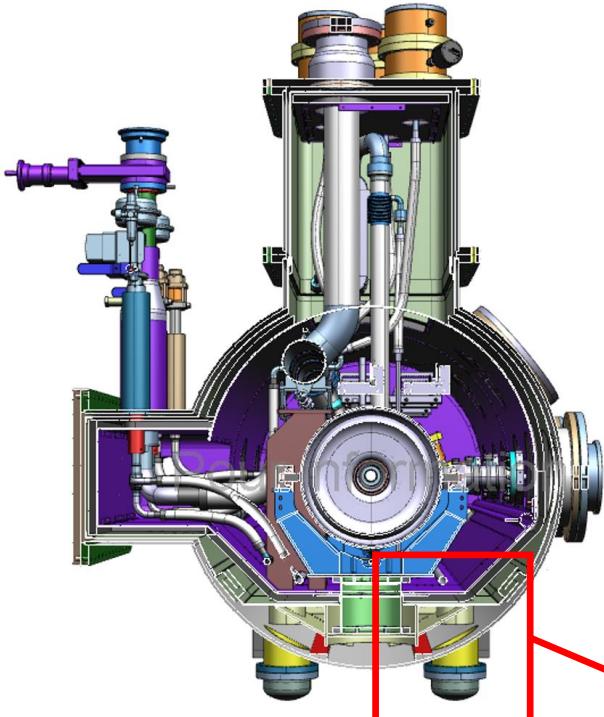
DE LA RECHERCHE À L'INDUSTRIE



Strongback: Thermal Studies

N. BAZIN

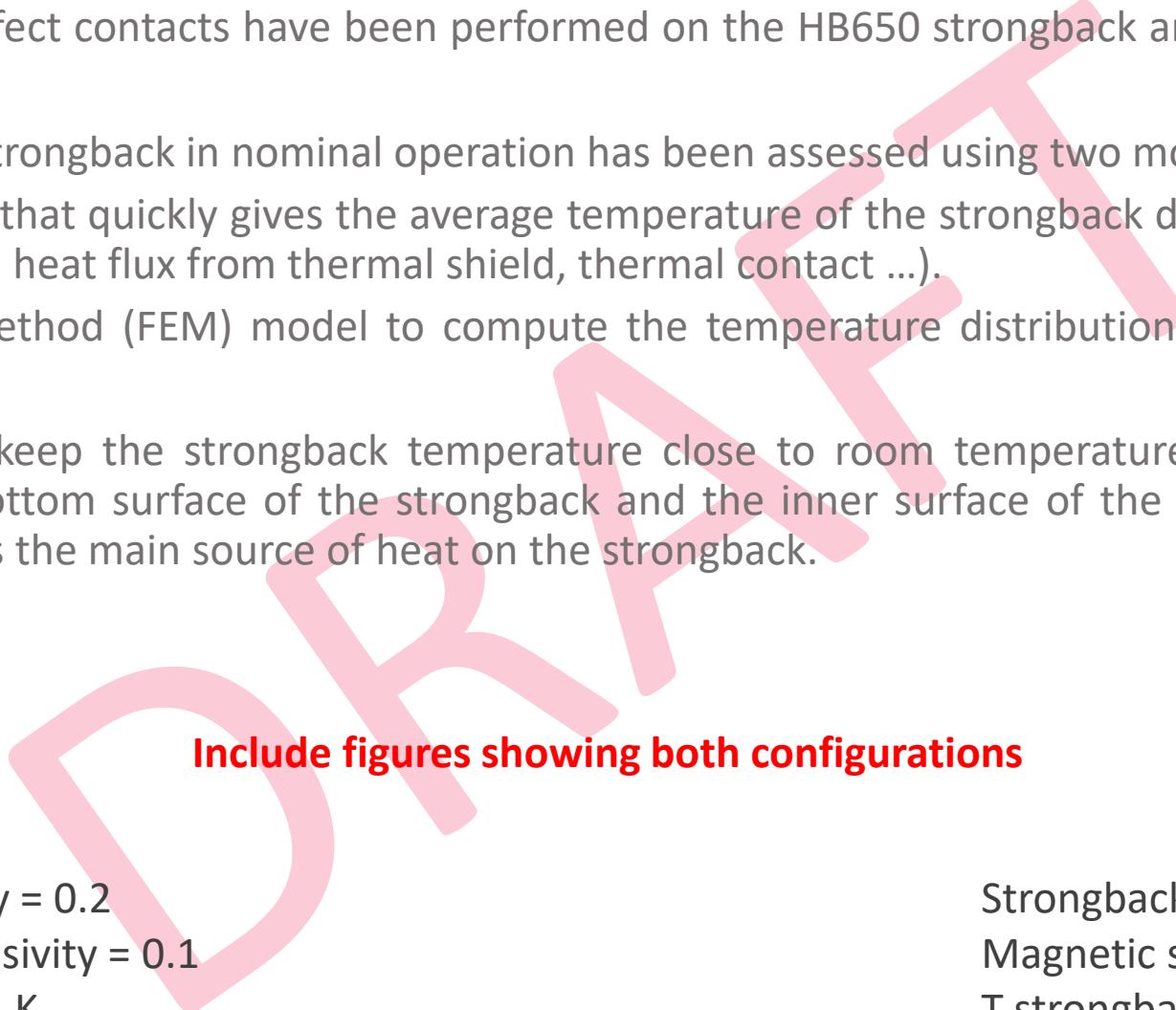
- ▶ Design concept: the cavity string is supported by the strongback that stays at room temperature
- ▶ The strongback is the key component for the alignment of the cavity string
- ▶ It is mandatory to assess its temperature taking into account all the heat loads that it receives
- ▶ Target: minimum value for the temperature of the strongback: 288 K (5K below room temperature)



Heat loads applied on the strongback:

- ▶ Conduction from the supporting posts of the dressed cavities with thermal intercept on the thermal shield
- ▶ Conduction from the supporting posts (studs) connected between the vacuum vessel and the strongback
- ▶ Radiation from the thermal shield at 50 K and covered with MLI
- ▶ Radiation from the vacuum vessel at room temperature (293 K)

- ▶ Thermal studies with perfect contacts have been performed on the HB650 strongback and presented at the Final Design Review in July 2020
- ▶ The temperature of the strongback in nominal operation has been assessed using two models:
 - An analytical model that quickly gives the average temperature of the strongback depending on several parameters (emissivity, radiation heat flux from thermal shield, thermal contact ...).
 - A Finite Element Method (FEM) model to compute the temperature distribution in the strongback and thermal gradients.
- ▶ **Conclusion:** in order to keep the strongback temperature close to room temperature, it is mandatory to have high emissivity of both the bottom surface of the strongback and the inner surface of the vacuum vessel, as the radiation from the vacuum vessel is the main source of heat on the strongback.



Include figures showing both configurations

Strongback: emissivity = 0.2

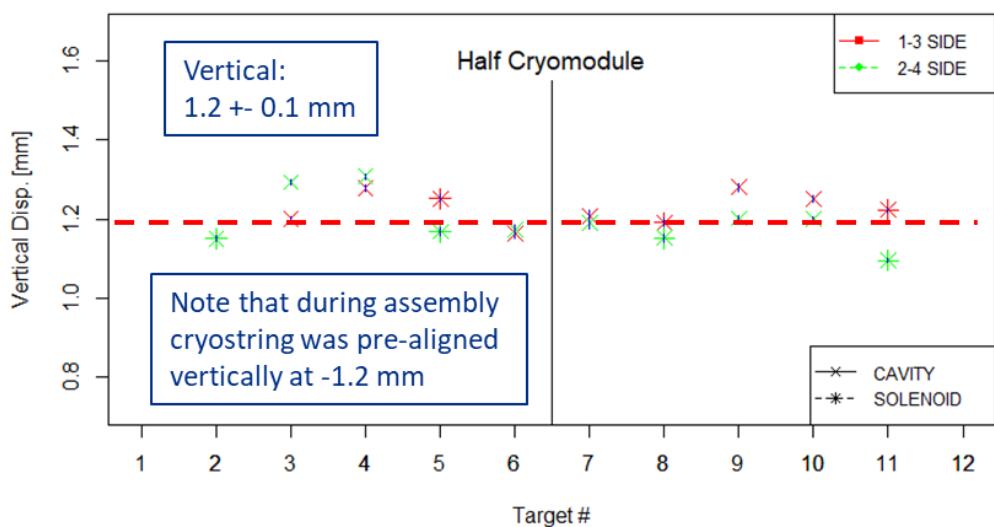
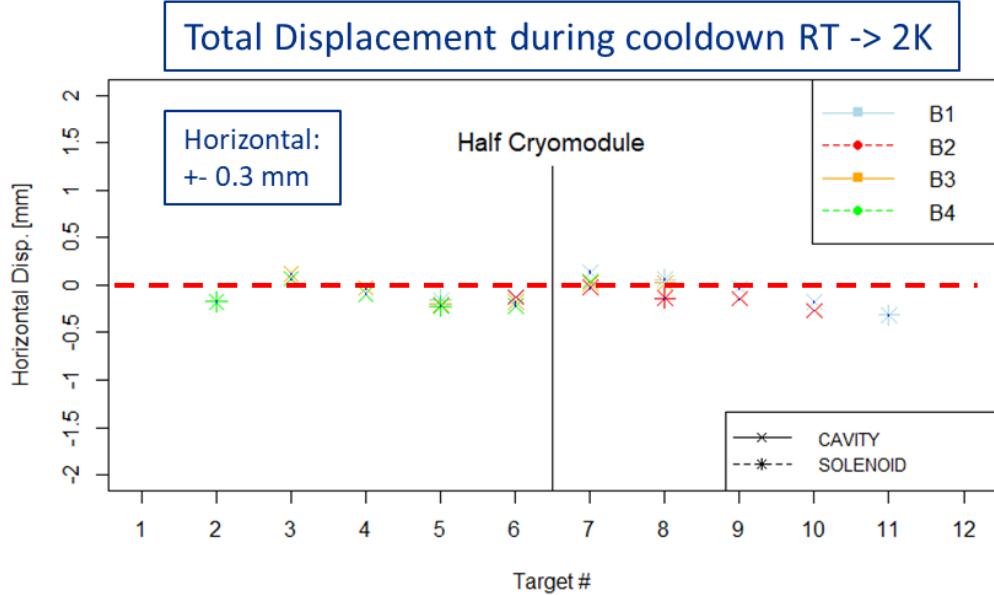
Magnetic shield: emissivity = 0.1

T strongback = 283.21 K

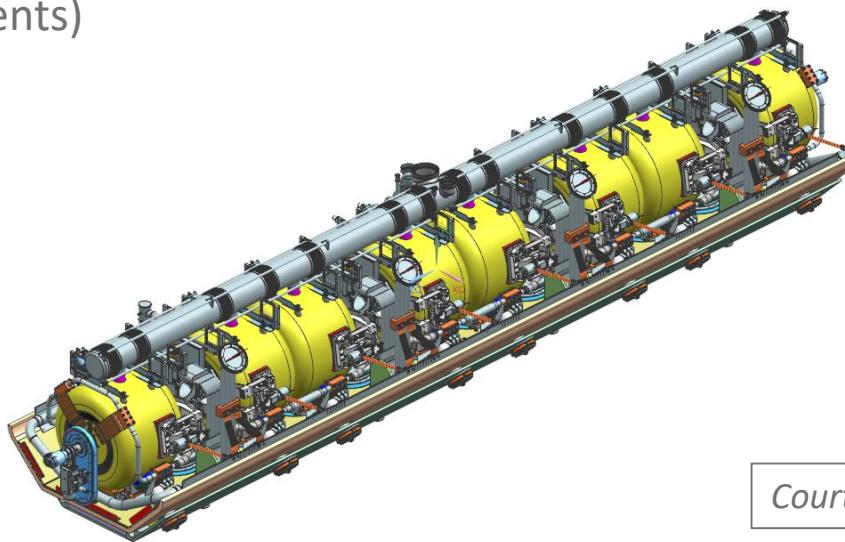
Strongback: emissivity = 0.7

Magnetic shield: emissivity = 0.7

T strongback = 291.22 K

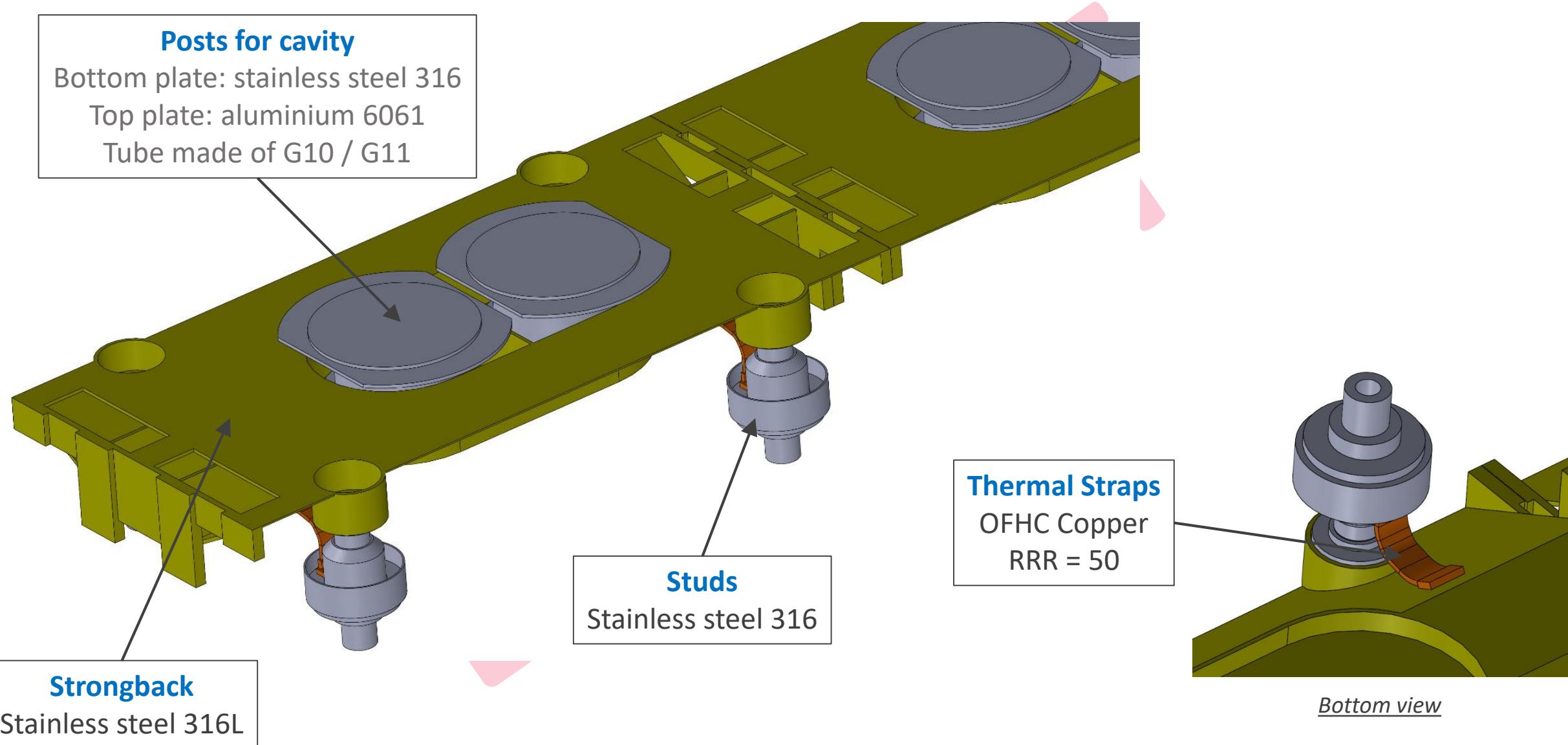


- ▶ Strongback principle
- ▶ Each cavity and each solenoid is supported by a post similar to the one used for the elliptical cryomodule
- ▶ The magnetic shield is installed on the inner surface of the vacuum vessel → heat load between the vacuum vessel and the strongback is limited by the low emissivity of mu-metal (around 0.1)
- ▶ During the cold tests at PIP2IT, the average temperature of the strongback was 268 K, with temperature gradient below 1 K
- ▶ The impact on the alignment of the cavity string of a strongback colder than expected is negligible (below the uncertainty from the HBCAM measurements)

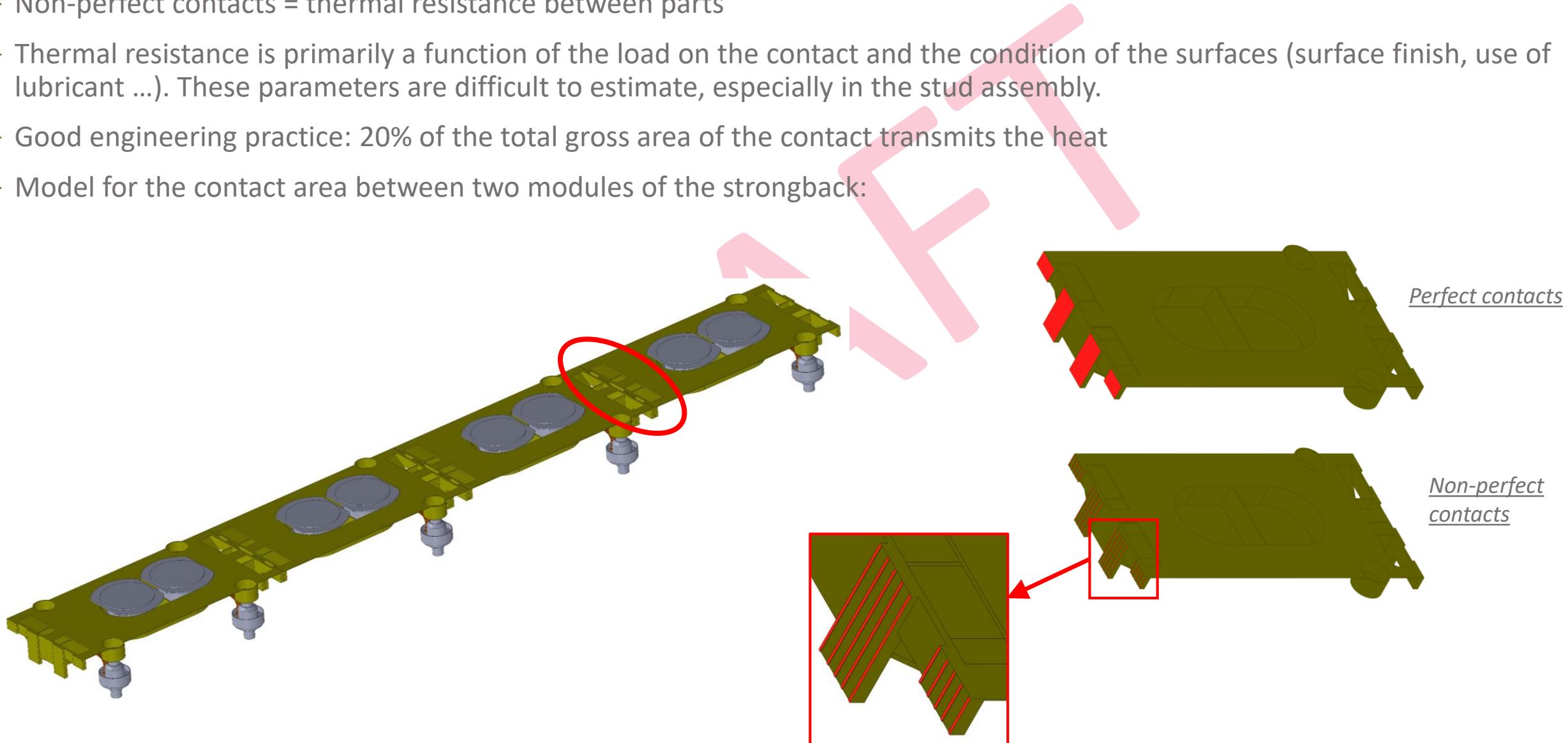


Courtesy of SSR1 team

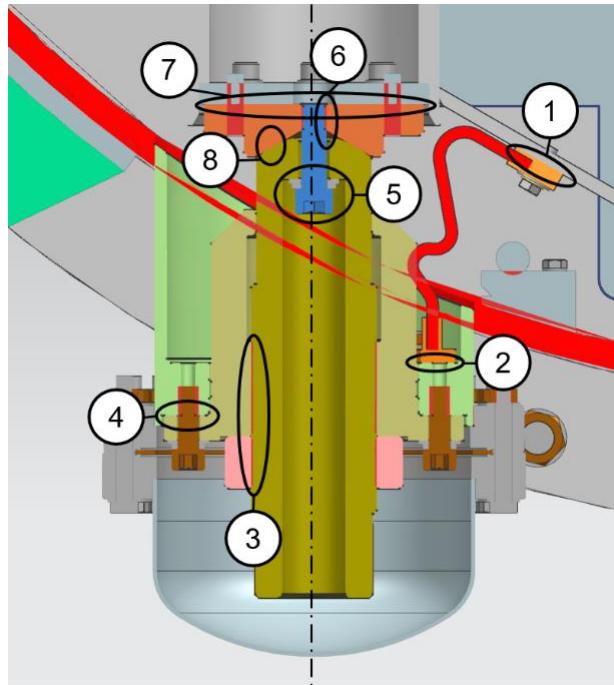
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- ▶ Non-perfect contacts = thermal resistance between parts
- ▶ Thermal resistance is primarily a function of the load on the contact and the condition of the surfaces (surface finish, use of lubricant ...). These parameters are difficult to estimate, especially in the stud assembly.
- ▶ Good engineering practice: 20% of the total gross area of the contact transmits the heat
- ▶ Model for the contact area between two modules of the strongback:



► Model for the stud assembly:

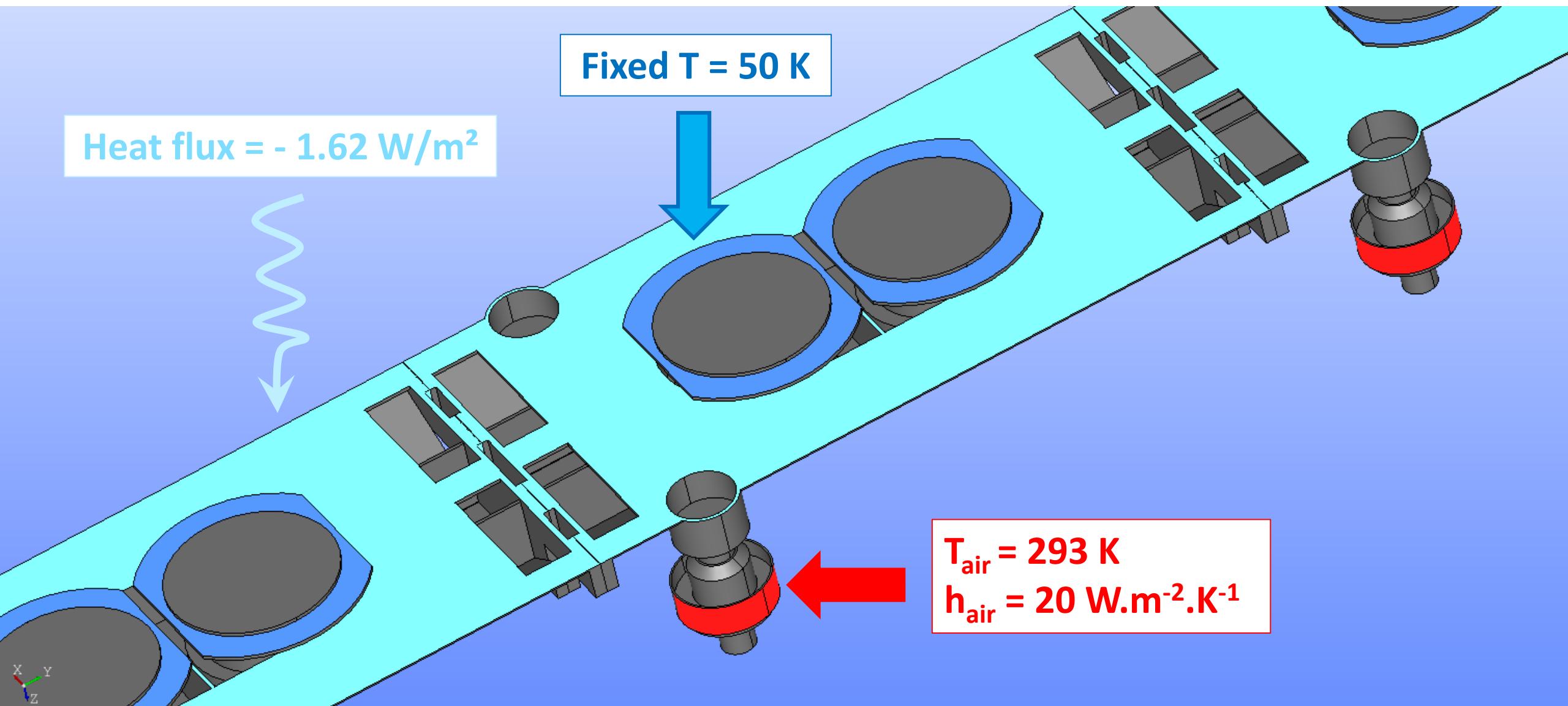


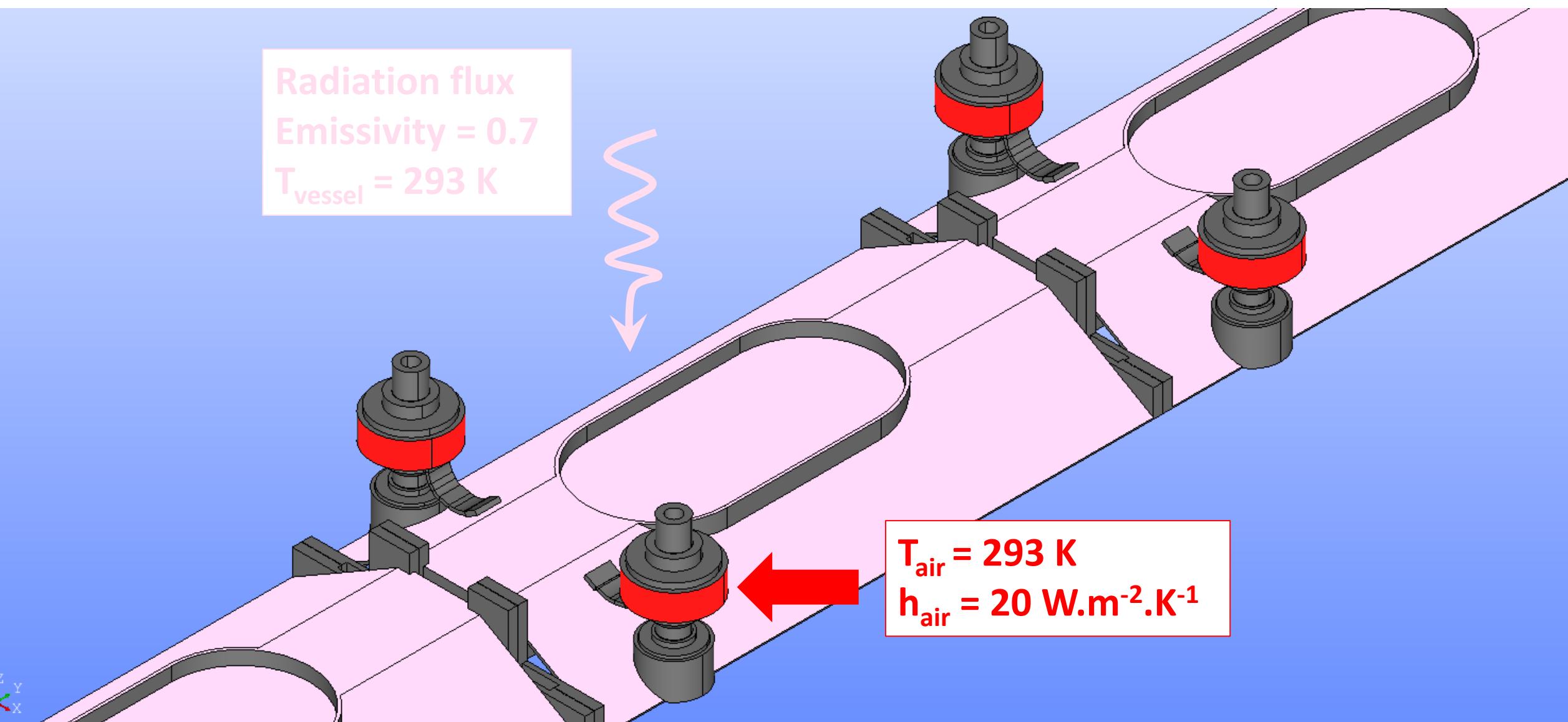
Contact number	Description
1	Perfect contact on all the contact surface between the thermal strap and the strongback
2	Perfect contact on all the contact surface between the thermal strap and the flange of the vacuum vessel
3	Perfect contact on 20% of the contact surface between the lock nut, the support nut housing and the threaded support
4	Perfect contact on 20% of the contact surface between the support nut housing and the flange of the vacuum vessel
5	Perfect contact on all the contact surface between the washers, the screw head and the threaded support
6	Perfect contact on 20% of the contact surface between the screw and the support plate with cone
7	Perfect contact on all the contact surface between the strongback and the support plate with cone because of the force due to the weight of the cold mass and the tightening force of the screws
8	No contact between the threaded support and the support plate with cone

Note: studies have been performed on the HB strongback with a non perfect contact between the strongback and the studs (contact number 7). The results show no big impact as the heat coming from the warm source – i.e the vacuum vessel – is small and limited by the contact surface of the washers, the screw head and the threaded support (contact number 5), which acts as a bottleneck for the heat transfer between the stud assembly and the strongback.

- ▶ Support posts of cavities: temperature of the surface connected to the thermal shield fixed to 50 K.
- ▶ Studs between the strongback and the vacuum vessel: connective heat load on the external surfaces in contact with ambient air:
 - Temperature: $T_{\text{air}} = 293 \text{ K}$
 - Heat transfer coefficient: $h_{\text{air}} = 20 \text{ W.m}^{-2}.\text{K}^{-1}$ (natural convection)
- ▶ Radiation from the thermal shield: fixed flux of 1.62 W/m^2 applied on the top surface whatever the temperature of the strongback.
- ▶ Radiation from vacuum vessel at room temperature (293 K): procedure of the FEM software considering infinite plane, with similar emissivity of 0.7 for both the strongback and the vessel. Radiation load applied on the bottom surface of the strongback.

Figures with details on next slides





Influence of contact between the studs and the strongback

► Thermal straps not taken into account in this study

	Emissivity $\epsilon=0.1$			Emissivity $\epsilon=0.2$			
	No studs	Bad contacts	Perfect contacts	No studs	Bad contacts	Perfect contacts	
Module 1	Tmax (K)	280.133	283.144	283.147	287.18	287.842	287.843
	Tmin (K)	276.602	278.464	278.459	283.816	284.268	284.257
Module 2	Tmax (K)	280.195	282.798	282.805	287.199	287.756	287.754
	Tmin (K)	276.712	278.309	278.318	283.87	284.242	284.242
Module 3	Tmax (K)	280.345	282.797	282.81	287.244	287.753	287.756
	Tmin (K)	276.782	278.398	278.409	283.887	284.257	284.254
Module 4	Tmax (K)	281.446	284.427	284.458	287.982	288.719	288.735
	Tmin (K)	277.117	279.24	279.28	284.027	284.54	284.561
	Emissivity $\epsilon=0.5$			Emissivity $\epsilon=0.7$			
	No studs	Bad contacts	Perfect contacts	No studs	Bad contacts	Perfect contacts	
Module 1	Tmax (K)	291.203	291.264	291.262	291.889	291.918	291.916
	Tmin (K)	288.355	288.425	288.416	289.303	289.341	289.33
Module 2	Tmax (K)	291.206	291.262	291.263	291.892	291.916	291.917
	Tmin (K)	288.373	288.428	288.426	289.316	289.344	289.339
Module 3	Tmax (K)	291.213	291.268	291.268	291.895	291.919	291.92
	Tmin (K)	288.377	288.427	288.422	289.319	289.343	289.339
Module 4	Tmax (K)	291.541	291.652	291.656	292.115	292.167	292.169
	Tmin (K)	288.405	288.464	288.475	289.334	289.356	289.365



► The quality of the contact within the strongback assembly has a small influence on the temperature of the strongback

► Study performed on the model with bad contacts

	Emissivity $\epsilon=0.1$		Emissivity $\epsilon=0.2$		
	With thermal straps	Without thermal straps	With thermal straps	Without thermal straps	
Module 1	Tmax (K)	288.86	283.144	290.535	287.842
	Tmin (K)	281.909	278.464	285.291	284.268
Module 2	Tmax (K)	288.583	282.798	290.293	287.756
	Tmin (K)	281.552	278.309	285.176	284.242
Module 3	Tmax (K)	288.559	282.797	290.285	287.753
	Tmin (K)	281.621	278.398	285.188	284.257
Module 4	Tmax (K)	289.935	284.427	291.041	288.719
	Tmin (K)	283.341	279.24	285.934	284.54
	Emissivity $\epsilon=0.5$		Emissivity $\epsilon=0.7$		
	With thermal straps	Without thermal straps	With thermal straps	Without thermal straps	
Module 1	Tmax (K)	291.865	291.264	292.188	291.918
	Tmin (K)	288.561	288.425	289.399	289.341
Module 2	Tmax (K)	291.82	291.262	292.168	291.916
	Tmin (K)	288.552	288.428	289.398	289.344
Module 3	Tmax (K)	291.819	291.268	292.167	291.919
	Tmin (K)	288.55	288.427	289.396	289.343
Module 4	Tmax (K)	292.139	291.652	292.402	292.167
	Tmin (K)	288.701	288.464	289.468	289.356



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ADDITIONAL SLIDES

- ▶ There was a discussion within the collaboration on the value for the radiative heat flux.
- ▶ Several experimental data could be found:
 - Heat flux from 300 K to 80 K is $1 - 3 \text{ W/m}^2$ (5 W/m^2 when MLI is compressed) *
 - Measured on LHC cryostat: 1 W/m^2 **
 - Measured on XFEL prototypes cryomodules: 1.5 W/m^2 ***
- ▶ Value used by FNAL in the thermal study of SSR1 strongback: 1.62 W/m^2 → value used by CEA in the study for the elliptical cryomodules strongbacks.
- ▶ CEA usually uses 3 W/m^2 when designing cryomodules because of the many openings in the MLI blankets.

* "Heat transfer and cooling techniques", B. Baudouy, CERN Accelerator School (CAS) on Superconductivity, 2013

** "Cryostat design", V. Parma, CERN Accelerator School (CAS) on Superconductivity, 2013

*** "Thermal performance analysis and measurements of the prototypecryomodules of European XFEL accelerator - part I", X.L. Wang and al., Nuclear Instruments and Methods in Physics Research A, Volume 763, 1 November 2014, Pages 701-710

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